Underwater Scannerless Range Imager

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LONG-TERM GOALS

The long-term goal of the Underwater Scannerless Range Imager (USRI) project is to develop and demonstrate a prototype underwater range imaging system based on a scannerless range imaging technology developed at Sandia National Laboratory that can be used by divers or deployed on small unmanned underwater vehicles (UUVs) to detect/classify/identify targets during very shallow water (VSW) reconnaissance or mine countermeasures (MCM) missions in low-visibility environments. High quality composite images generated by fusing the range image with the usual optical image will provide the diver with an unprecedented capability to identify hazardous obstacles and ordnance at a safe standoff range. Three-dimensional target recognition algorithms to analyze the range image data will facilitate the accurate classification of underwater targets for systems deployed in small, unmanned underwater vehicles.

OBJECTIVES

The initial phase objectives are to: 1) Understand the effect of a highly scattering environment on the performance of the Sandia developed scannerless range imaging technology, 2) quantify system performance and verify analytical results through in-situ tank/dock tests of a bread-board system with electronics designed to adapt the current terrestrial system to performing the same function in the underwater environment. Subsequent objectives are to develop, test, and demonstrate range imager designs that adapt and optimize the range imaging technology to the underwater environment.

APPROACH

The scannerless range imaging technology developed by Sandia National Laboratory employs an intensified CCD receiver operating in conjunction with an active illumination source. Three-dimensional target images, or range images, are produced through a technique that involves the pre-detection mixing in a gain-modulated microchannel plate of the backscattered return generated by a modulated illumination source that is synchronously modulated with the gain of the receiver. The captured phase information associated with the return off a target that is generated through this process allows the calculation of receiver-to-target range on a pixel-by-pixel basis. The approach offers potential advantages for underwater imaging applications since the phase information used to construct the 3-D target images will be preserved under conditions that would render target recognition impossible in a 2-D reflectance image.

The team's approach has been to utilize both modeling/analysis and bench-top hardware data collections to further understand the potential capability that will be provided by a USRI system. An existing imaging model has been modified to explore the effects of blur-glow, non-uniform laser illumination, and non-uniform scattering on the range imagery. However, less stringent methods are adequate to explore the effects of the laser power, range-gate width, gain modulation frequency, and water attenuation. The modeling work is being used to provide guidance for the design of components that will facilitate the adaptation of the scannerless range imaging technology to the underwater environment, and to help design the experiments that will provide the data required to evaluate the potential underwater performance of the scannerless range imaging technology. The experimental data is, in turn, being used to further refine the models and demonstrate the performance capabilities of the USRI system. Analysis of the experimental data provides the information required to both validate the models and define the system parameters required for the optimization of the USRI's performance.

WORK COMPLETED

Work completed during the current fiscal year included 1) the fabrication of- and initial experiments with a version of the scannerless range imager designed specifically to evaluate operational characteristics of the system in the underwater environment; 2) completion of the first implementation of an imaging model, which includes the effects of critical environmental variables, and which has the ability to generate synthetic range images that reflect the effects of environmental degradation on the image; and 3) collection and analysis of the data from the experiments in the SDV test tank for a wide range of parameters which effect the quality of the collected range images.

Earlier tests at the Coastal Systems Station (CSS) revealed that the image quality was sensitive to the gating technique employed, specifically that the back-scatter energy could be more easily discriminated if the power supply were able to turn on and off more efficiently. Additional electronics were developed and fabricated to satisfy this requirement and to enhance the programmability of the sensor electronics, making the sensor more flexible through computer control of gate timing relative to laser pulse emission. This circuitry included a serial protocol interface for commands, programmable control of power supply and bias voltages, programmability of gate operations, temperature sensing, modulation filter switching, and support for a broader range of modulation frequencies. Existing USRI system software was modified to support the programmable features of the sensor electronics and the programmable waveform generator that was used during the experiments. The code previously supported both the waveform generator and the programmable sensor electronics, but changes specific to the USRI project were implemented to support the CSS tank tests.

The USRI hardware was integrated into a submersible enclosure designed to provide the capability to test the system at depths up to 100 ft. Testing with the resulting configuration was actually limited to a depth of 40 feet due to bandwidth-imposed limitations on the length of the data cables. The enclosure consists of cylindrical PVC pipe capped at both ends by optically transparent acrylic bulkheads. External power supplies and data collection devices were connected to the range imager through a 1½” ID umbilical cable attached to the rear bulkhead of the enclosure. An internal cooling system consisting of an internal pump and an external stainless steel heat exchanger was installed in the enclosure to remove the heat generated by the Big Sky CFR 400 Nd:YAG laser source which produced 160 mJ/pulse at an operating frequency of 30 Hz. A breakout of the system components before and after integration are shown in Figure 1.

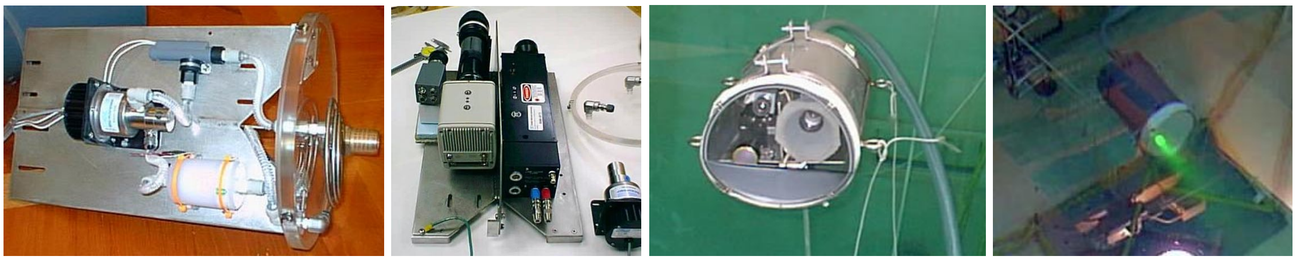
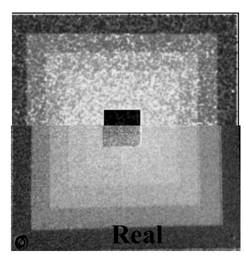


Figure 1. USRI Cooling System, EO Components, Enclosed USRI Floating in the SDV Test Tank, and USRI Operating Submerged During Tests.

A total of 73 separate experiments were conducted in the CSS SDV test tank to evaluate the effects of gate timing and modulation frequency on the quality of the range images. Five receiver modulation frequencies were used – 10.417 MHz, 13.889 MHz, 20.833 MHz, 27.778 MHz, and 41.667 MHz. Minimum gate rise times and widths were on the order of 10 ns. However, these parameters could be varied over a substantial range of operating values. Data from these experiments were subsequently analyzed by all three of the participating research groups.

Implementation of a USRI imaging model based on the facet-model utilities and the view-rendering module of the ladar channel (Lender) from the Air Force’s Irma synthetic image generation code was completed. The propagation model includes the effects of backscatter from the turbid medium, spreading and attenuation of the illumination beam by scattering and forward diffraction around obscurant particles, and reflection by the target. Separate temporal profiles are assigned to five channels corresponding to backscatter from the medium and four path-types depending on whether the light is or is not scattered within the medium on its way to or from the target. These temporal profiles are summed and integrated with a response kernel derived from impulse responses for the gain-modulated microchannel plate and for the decay of light from the phosphor screen excited by the output from this MCP. The sensor model also accommodates a Gaussian point-spread function and digitization of the final image.



Synthetic

RESULTS

A total of 73 separate experiments were performed with the system operating in a total of six different modes. Modes 1-5 are associated with the receiver gain being sinusoidally modulated at the five respective frequencies cited earlier. Mode 6 is a more complex operating condition that involves using a combination of two of the receiver modulation frequencies to generate the range image. Thirty-degree phase increments relative to the transmitter were normally used to generate the range images. There were also a number of tests performed in which a combination of fixed and stepped phase increments was employed to generate the range images. In this case, a portion of the modulation was shifted in thirty-degree increments, and a portion of the modulation was fixed in phase relative to the transmitter output. In most cases, a total of 12 intensity images were used to derive each range image. Four different fields of view (FOV) were employed with the receiver, i.e., the FOV for tests 1-8 was 8.7°, the FOV for tests 9-35 was 10.3°, the FOV for tests 36-52 was 17.3°, and for tests 53-73, the FOV was 22.5°. Several gate-timing combinations were used during the tests, and analysis of the data showed that the quality of the images varies substantially with the gate-timing selection.

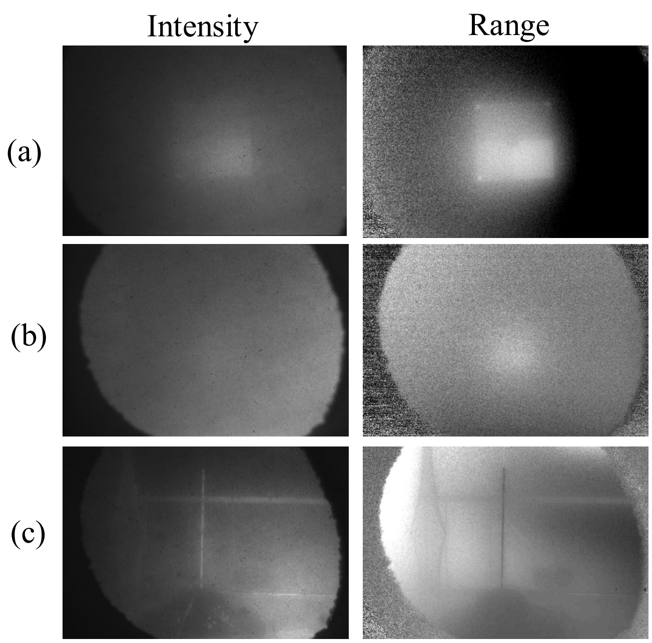


Figure 2

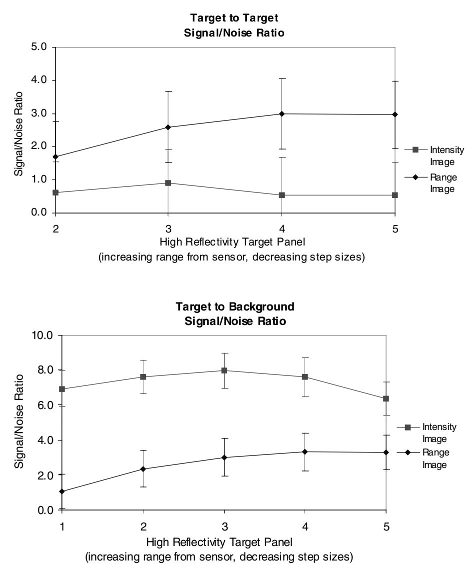


Figure 3

Figure 2, which is a collection of range and intensity images from three of the imaging tests, illustrates the kind of image data that was collected during the series of tests. The range resolution panel in the upper figures (a) was 4.55 attenuation lengths from the receiver. Mode 2 modulation and 30° phase increments were used to form the range image. In figure 2 (b), the target is 8.13 attenuation lengths from the receiver, and Mode 2 modulation with a combination phase scheme was used to construct the range image. The bottom image pair contains various targets located at different distances from the receiver. A thorough analysis of the entire data set is presented in a draft data analysis report written by the Sandia research group. Note that the range image in Figure 2 (b) implies target detection at a distance of 8 attenuation lengths. Figure 3 is a comparison of relative image signal-to-noise ratio (SNR) for a conventional range-gated imager to a scannerless range imager for the cases of a target in a high contrast environment (bottom) versus a low contrast target (top). The clear implication here is that the USRI provides a distinct advantage when viewing low contrast targets.

IMPACT/APPLICATIONS

The USRI is a frame imaging system and requires no platform stabilization. The system gates out the volume backscatter in the same manner as a conventional range-gated image, and the range processing acts to reduce the blur glow effects that limit the performance of other types of imagers. The USRI provides high spatial resolution three-dimensional data and two-dimensional reflectance maps simultaneously. These products can be used in combination with each other to provide a powerful discriminator for mine identification.[1] Sandia is currently developing the range imaging capability in a palm size package for space applications. Scaling the technology to this small size will provide a tremendous advantage over most existing laser imaging systems.

The Special Operations Command is currently planning to procure a number of small underwater Semi-Autonomous Hydrographic Reconnaissance Vehicles (SAHRV) developed by the Woods Hole Oceanographic Institute (WHOI). These vehicles, based on the Remote Environmental Underwater Surveying (REMUS) vehicle, are approximately 7.5 inches in diameter by 54 inches in length, and weigh less than 100 pounds in air. A series of demonstrations, culminating in a successful debut in Fleet Battlelab Experiment – Hotel (FBE-H), have shown SAHRV and similar vehicles to be capable of autonomously collecting bathymetric information and performing mine reconnaissance for small search areas in very shallow water environments. Other autonomous platforms participating in the same exercise demonstrated a limited ability to reacquire targets and collect image data using simple image recording devices. The image data was reviewed at the end of each mission, and mines could be identified in many cases. A substantial amount of image data was collected in areas where visibility was too poor to successfully identify any of the targets. In these cases, it was evident that more capable electro-optic imaging systems will be needed to identify targets in more turbid environments.

TRANSITIONS

The ideal transition point for this program is into the VSW MCM 6.3 technology development program after a prototype has been successfully demonstrated. A particularly desirable transition path involves integration of the USRI into an autonomous platform such as the Battlespace Preparation Autonomous Vehicle (BPAUV) and demonstrating its potential against actual targets in the shallow water and very shallow water environments. An opportunity to consider the integration of the USRI into the BPAUV is expected to be available during FY02.

RELATED PROJECTS

The SEAL camera (SEACAM) is an ONR sponsored project that has the objective of producing a small underwater imaging and ranging device specifically for divers. The current configuration combines a sonar range finder with the digital camera. Laser diodes are used for illumination and a polarization filter oriented transverse to the polarization orientation of the laser source is used to minimize the effects of volume backscatter. The range information is used in combination with the known field of view of the camera to calculate the size of the target on the basis of the calculated size of the pixels covering the target. The Shallow Water Imaging Polarimeter (SHRIMP) is an ONR-sponsored passive underwater imaging system that simultaneously collects and co-registers optical image information for three different scene polarization states. Preliminary in-water tests of the SHRIMP are slated to take place during the latter part of FY00. Larger developmental systems include the Streak-Tube Imaging Lidar (STIL) and the Electro-Optic Identification (EOID) sensor.

REFERENCES

1. C. Diegert, J. Sackos, and R. Nellums, 1997. Building Accurate Geometric Models from Abundant Range Imaging Information, Laser Radar Technology and Application, *Proceedings of SPIE*, Vol. 3065.